Safer Spray-Foam Insulation

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image from sprayfoam.org

Goal: Identify safer alternatives to MDI-based spray foam and create frameworks to evaluate their technical performance and potential health impacts.

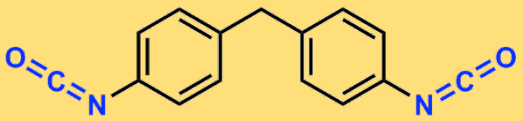
Key Functional Properties

- Insulation
- Longevity
- Sprayability
- Status-quo compatibility
- Fire, mold, & pest resistance
- Material cost

Spray Polyurethane Foam (SPF)

A-Side

MDI



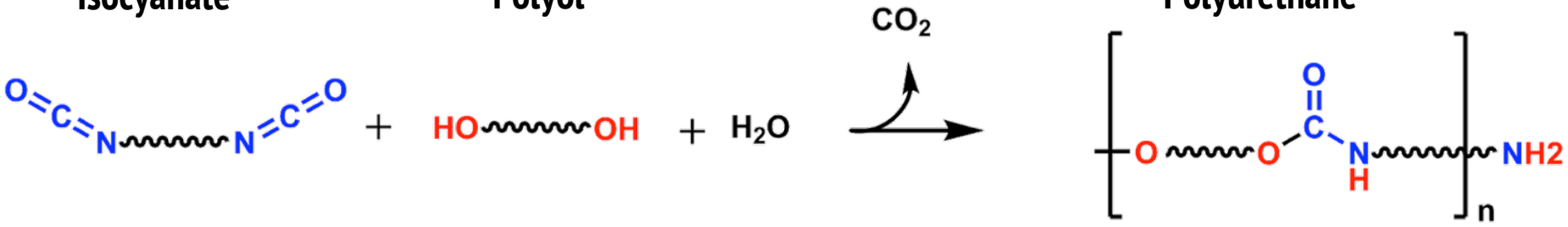
B-Side

polyols

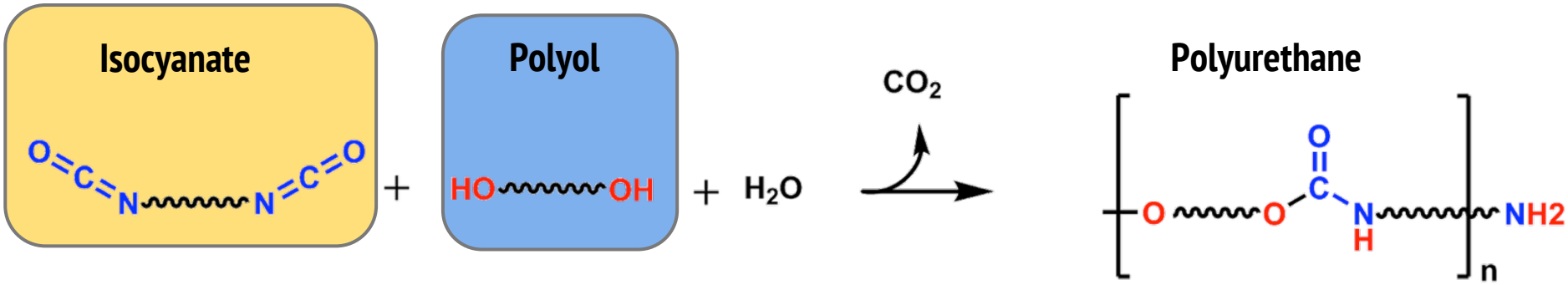
- blowing agents
- surfactants
- flame retardants
- catalysts

SPF: How it works

Isocyanate + **Polyol** + H_2O → (CO_2 ↑) → **Polyurethane**



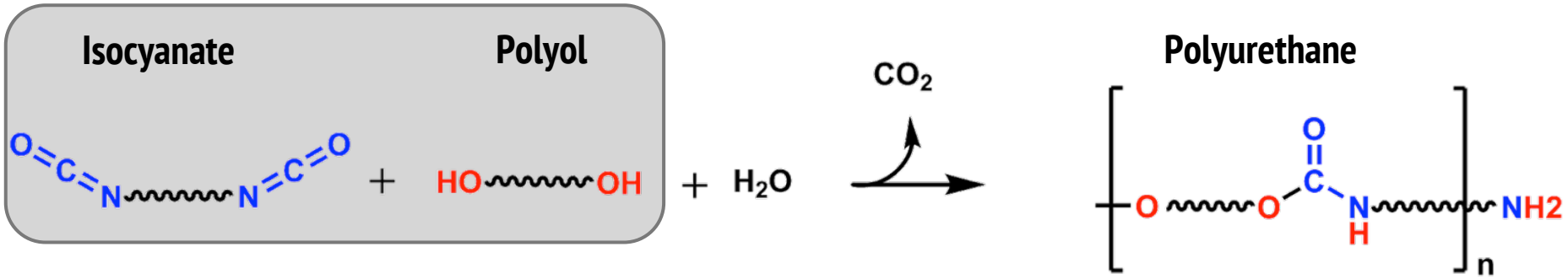
SPF: How it works

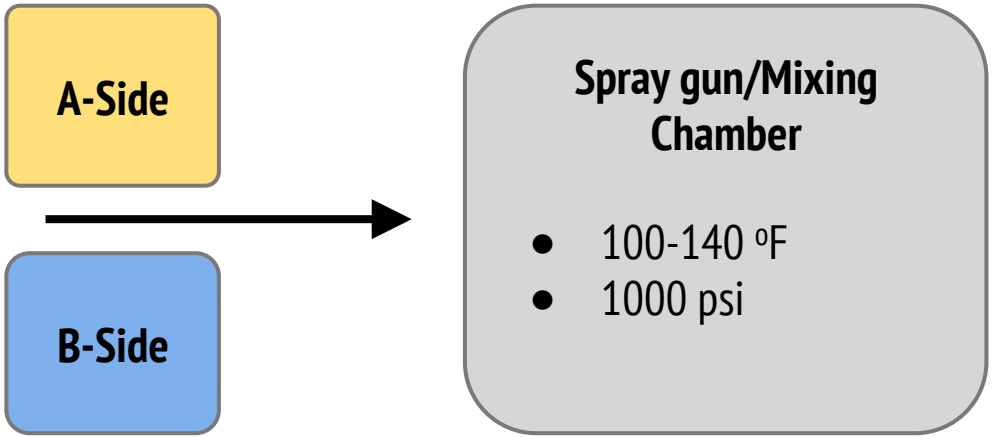


A-Side

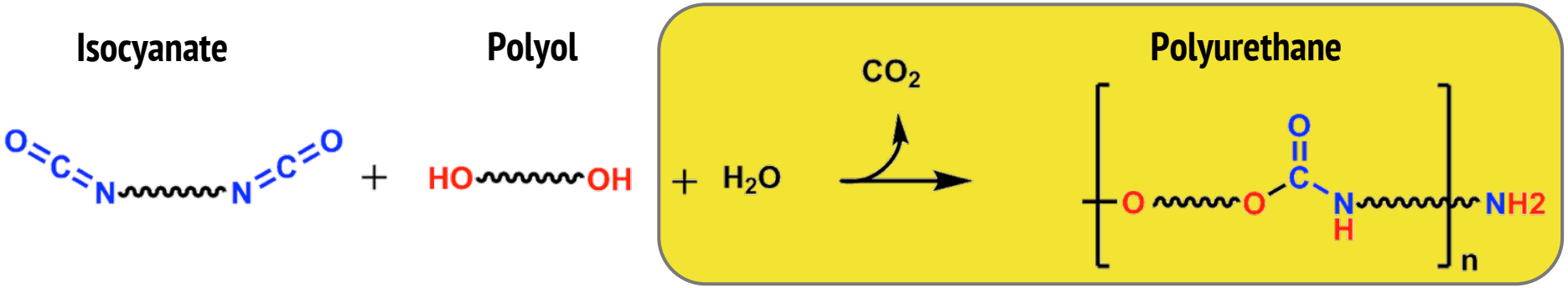
B-Side

SPF: How it works





SPF: How it works



A-Side

B-Side

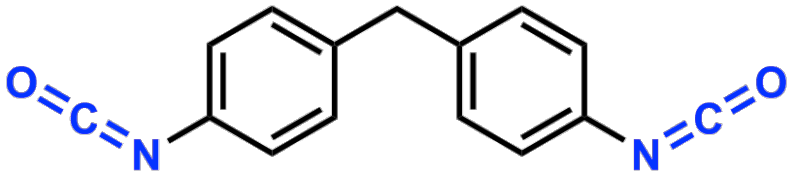
Spray gun/Mixing Chamber

- 100-140 °F
- 1000 psi

SPF

SPF Health Hazards

SPF Application

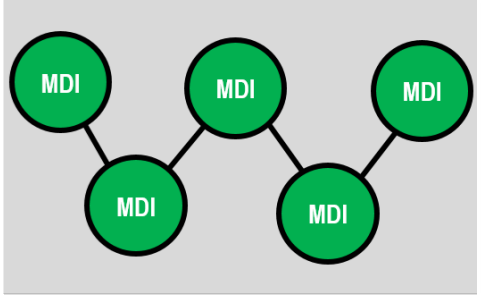


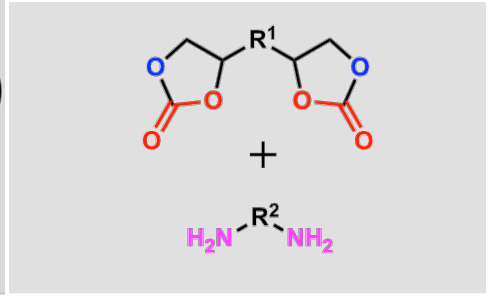
Methylene Diphenyl Diisocyanate (MDI)

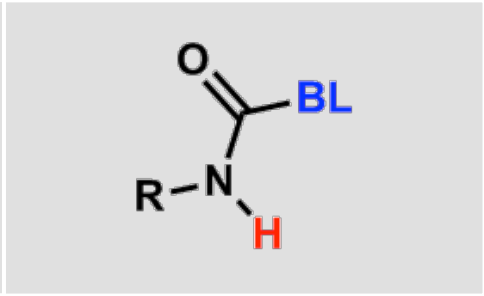
xposure (ppb)

- Respiratory sensitizer
  → occupational asthma
- Skin sensitizer
  → Systemic sensitization
  → asthma upon subsequent MDI inhalation exposure

image from fpnotebook.com

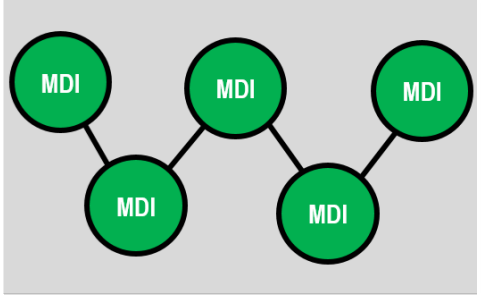


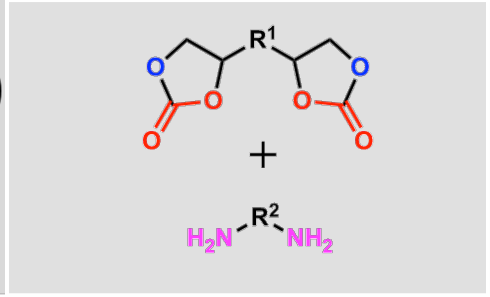


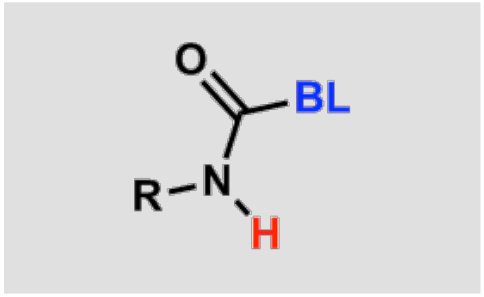


Alternatives

images from societyforsicence.org, staticflickr.com, exteriorsofiansing.com, wageningenur.nl, ibtimes.com







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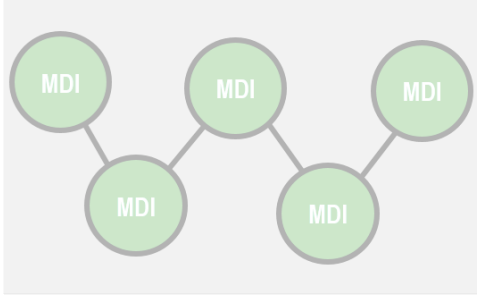

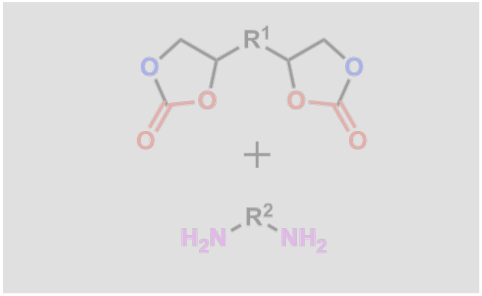

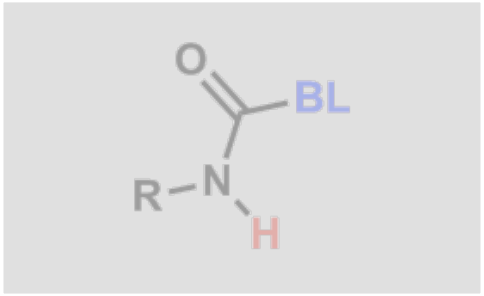

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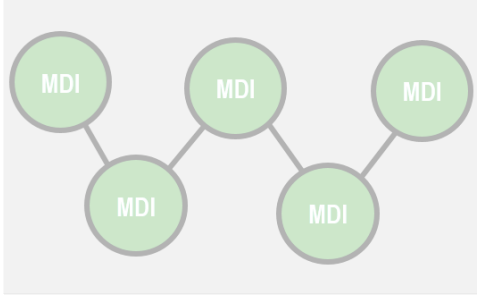

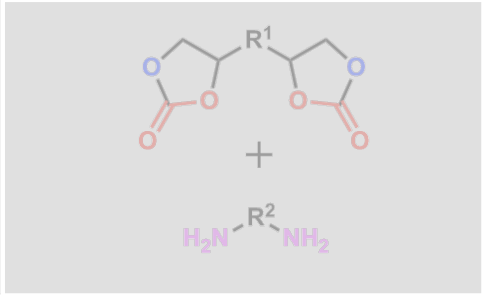

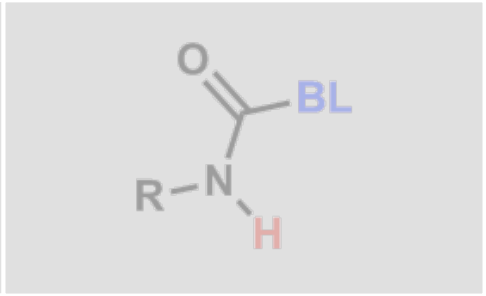

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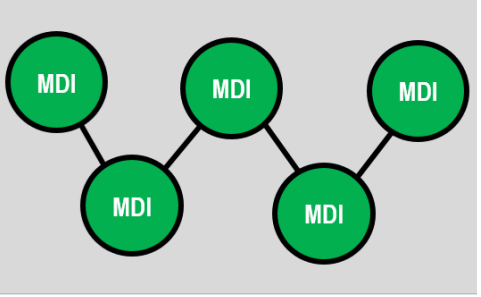
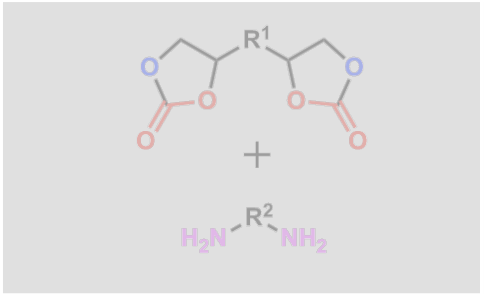
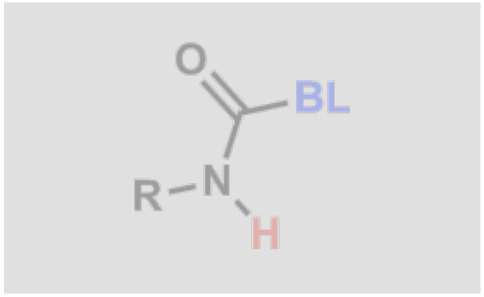
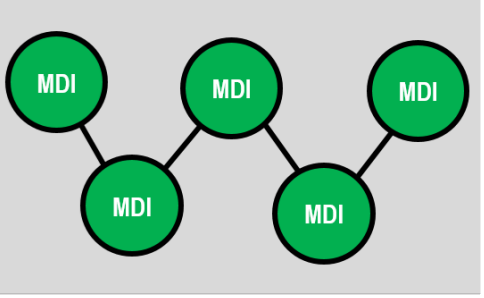






Polymeric MDI (pMDI)

images from societyforsicence.org, staticflickr.com, exteriorsoflansing.com, wageningenur.nl, ibtimes.com



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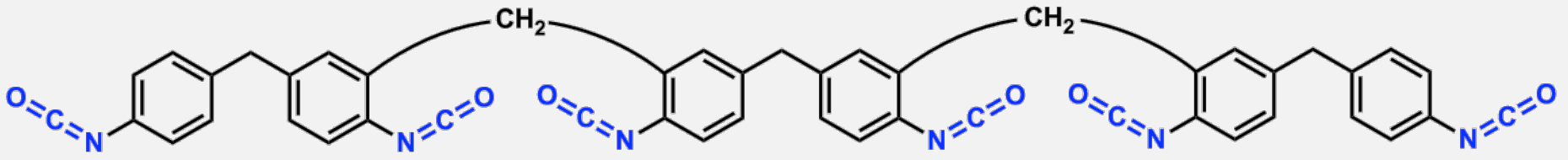
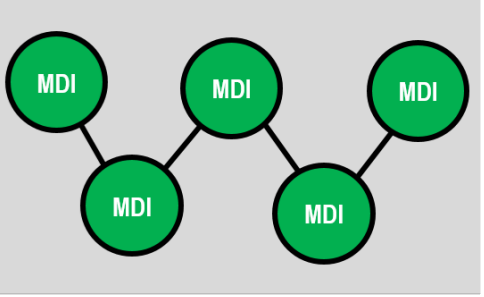


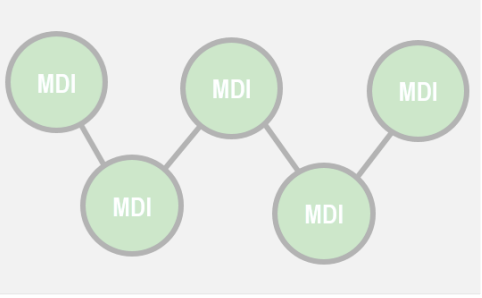
pMDI is a polymeric form of MDI with unreacted isocyanates

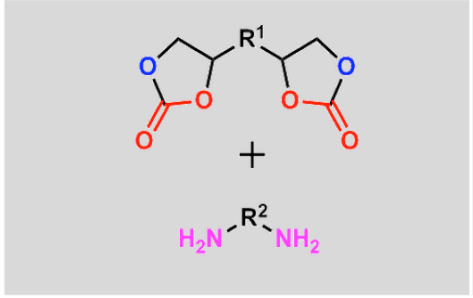
lower vapor pressure than MDI

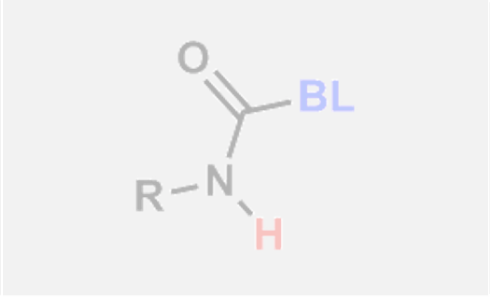


Polymeric MDI (pMDI)

- Commercially available (purifiable by size exclusion chromatography)
- Less bioavailable than MDI
- Smaller (but non-zero) likelihood of off-gassing free isocyanates

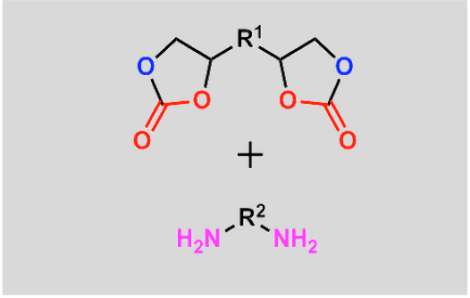




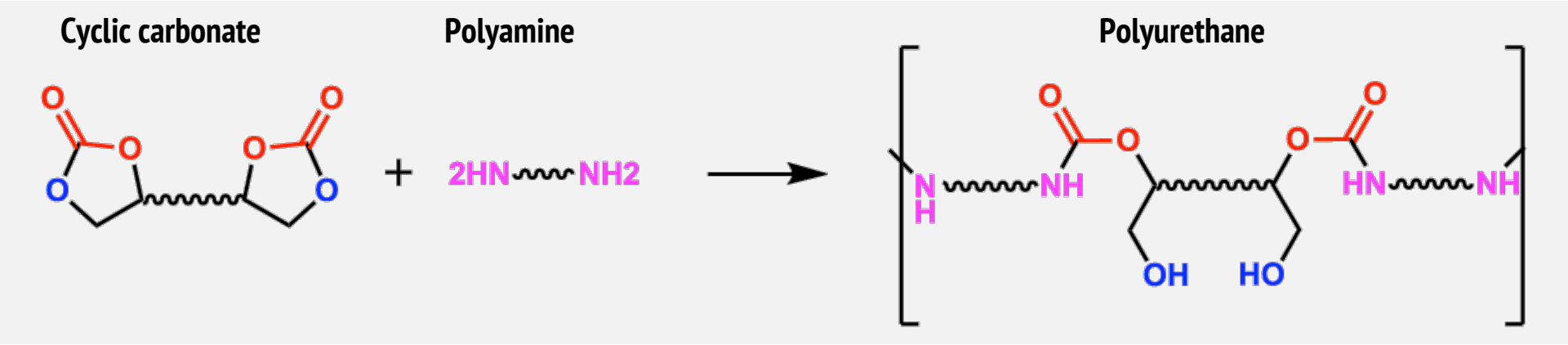


Non-isocyanate Polyurethane (NIPU)

images from societyforsicence.org, staticflickr.com, exteriorsoflansing.com, wageningenur.nl, ibtimes.com

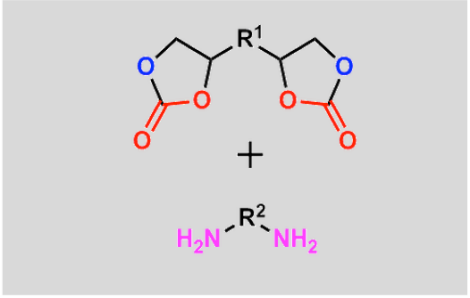


Non-isocyanate Polyurethane (NIPU)



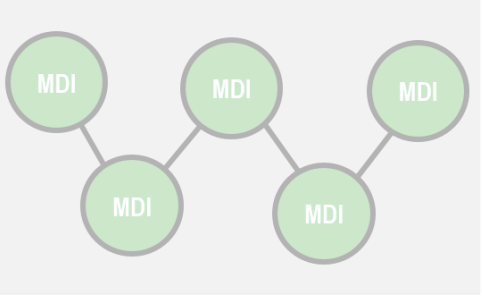
NIPU is the **same** polyurethane!

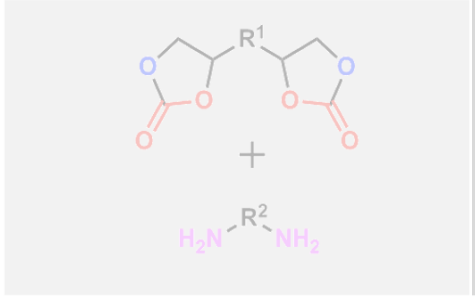
“cyclic carbonate” + “poly-amine” = polyurethane

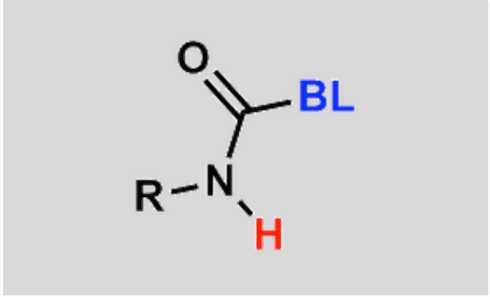


Non-isocyanate Polyurethane (NIPU)

- Chemicals can be less hazardous
- Tested successfully with standard Graco spray reactors (Nanotech Industries)

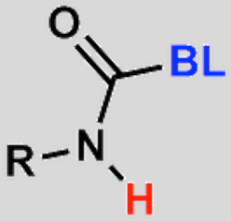




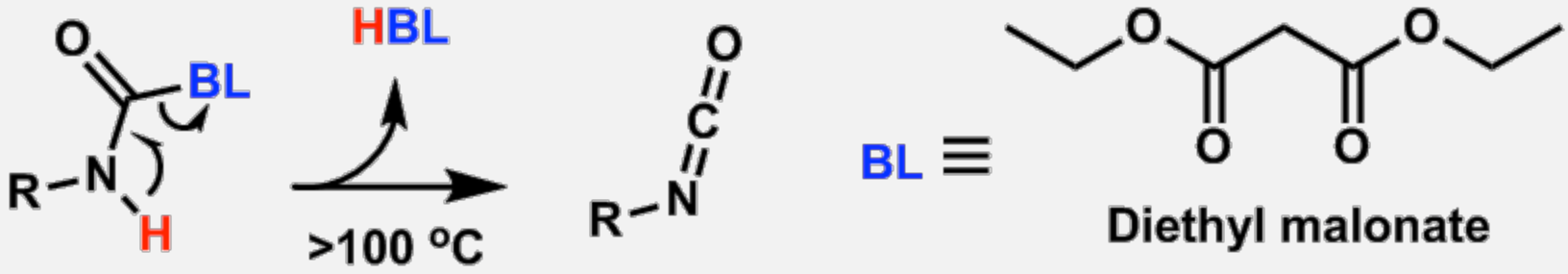


Blocked Isocyanates

images from societyforsicence.org, staticflickr.com, exteriorsoflansing.com, wageningenur.nl, ibtimes.com

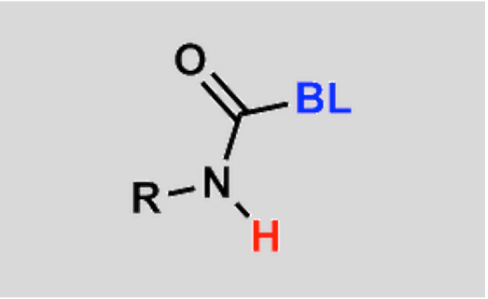


Blocked Isocyanates



isocyanate + “blocking group” = “blocked (unreactive) isocyanate”

“unblocking” only occurs at high temperature (>100 °C)



Blocked Isocyanates

A-Side

B-Side

HO OH

Spray onto surface

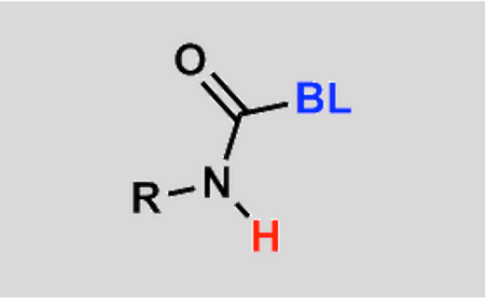
HO OH

Heat surface

HBL

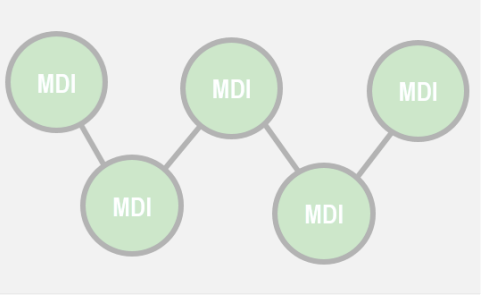
HO OH

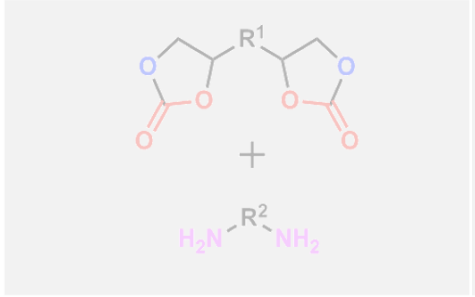
SPF

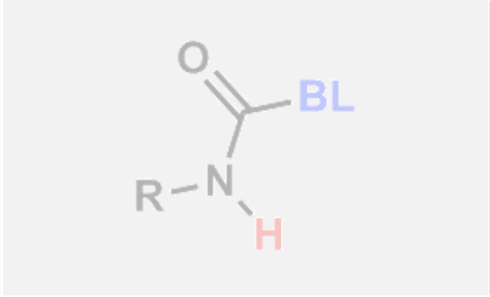


Blocked Isocyanates

- Smaller chance of free-isocyanates during application
- Application would require heating of installed foam



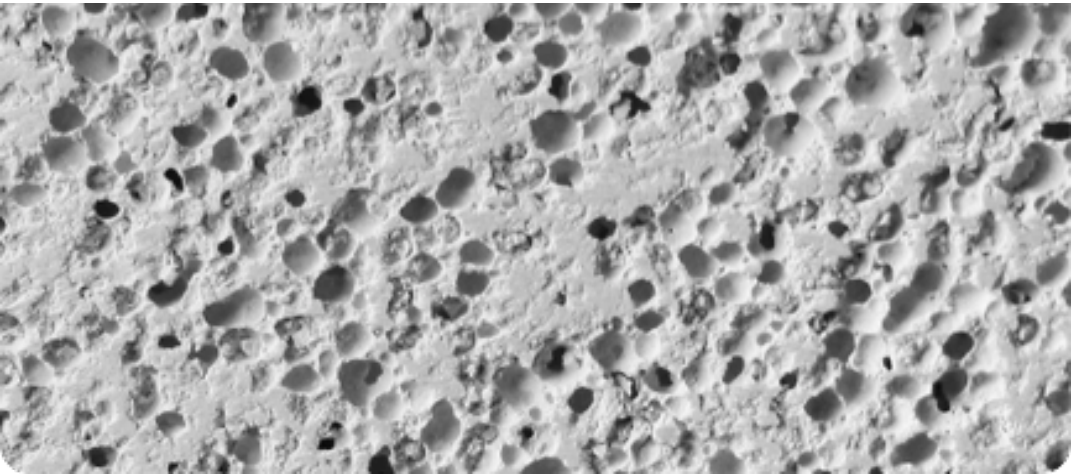




Foamed Concrete

images from societyforsicence.org, staticflickr.com, exteriorsoflansing.com, wageningenur.nl, ibtimes.com

Foamed Concrete

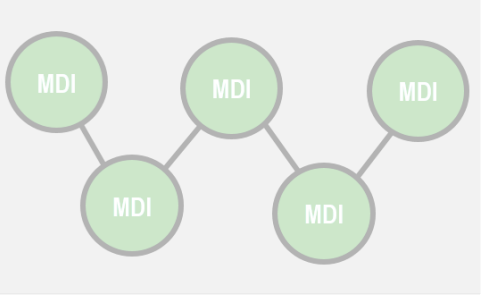


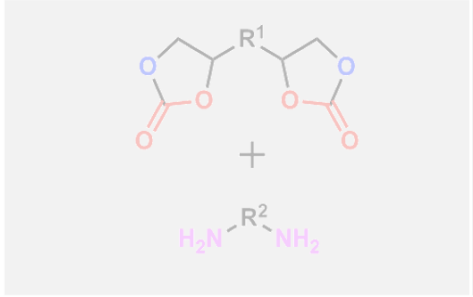
H_2O + MgO + polyvinyl alcohol + 1% barium metaborate + 1% dispersant

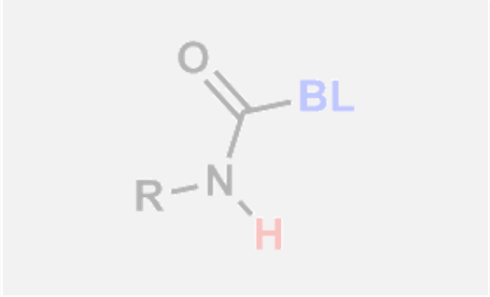
images from aircrete-europe.com, exteriorsoflansing.com

Foamed Concrete

- Existing product, similar application
- More stable / longer life
- Inherently fireproof
- Lower R-value
- Similar or lower cost







Cellulose Spray

images from societyforsicence.org, staticflickr.com, exteriorsoflansing.com, wageningenur.nl, ibtimes.com

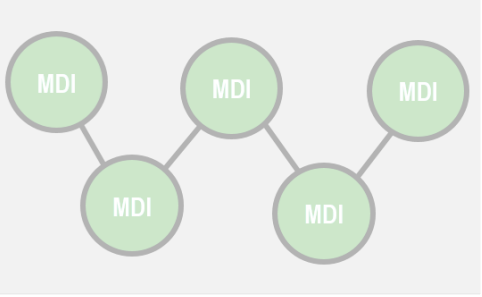
Cellulose Spray

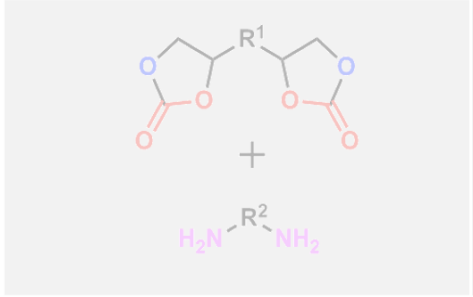
Recycled newsprint + polyvinyl alcohol + boric acid

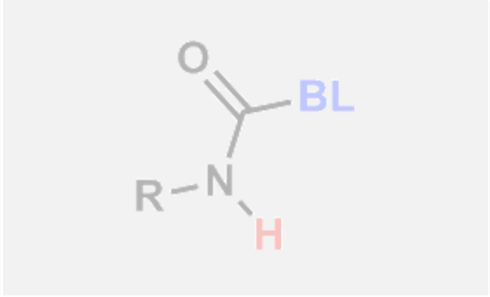
images from aircrete-europe.com, exteriorsoflansing.com

Cellulose Spray

- Less expensive
- Easier to apply
- Less toxic when burned
- Lower insulation value



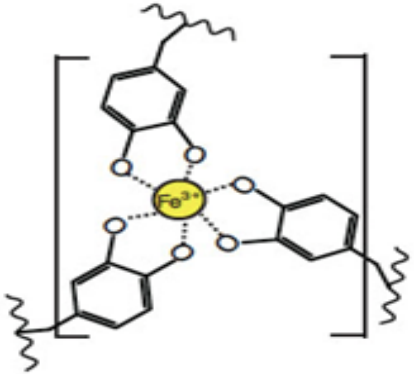




Protein Crosslinking

images from societyforsicence.org, staticflickr.com, exteriorsoflansing.com, wageningenur.nl, ibtimes.com

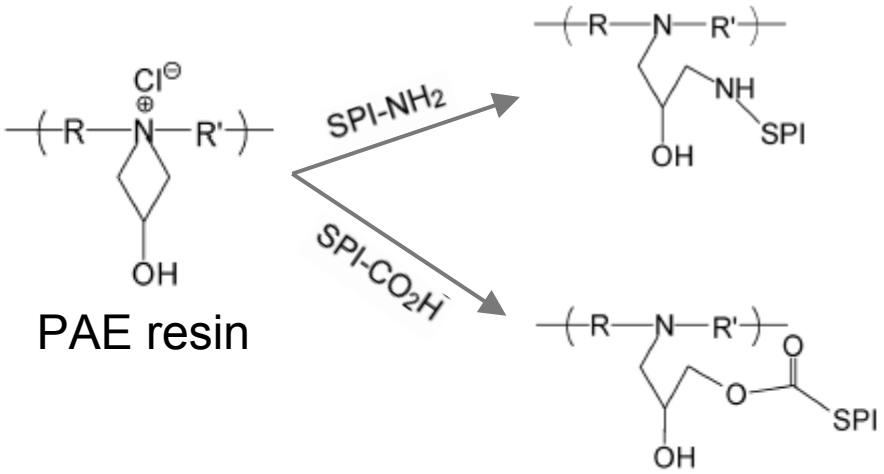
Protein Crosslinking



Strategy: Modify amino acid side chains for crosslinking

Protein Crosslinking

Commercial example: Soyad



Li et al. 2004. JAOCS.

image from globalimporter.net

Protein Crosslinking

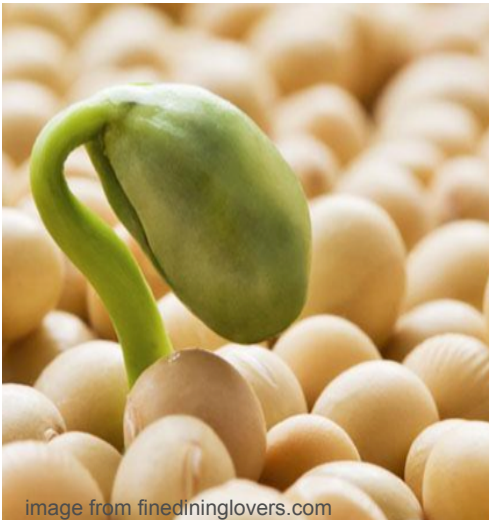


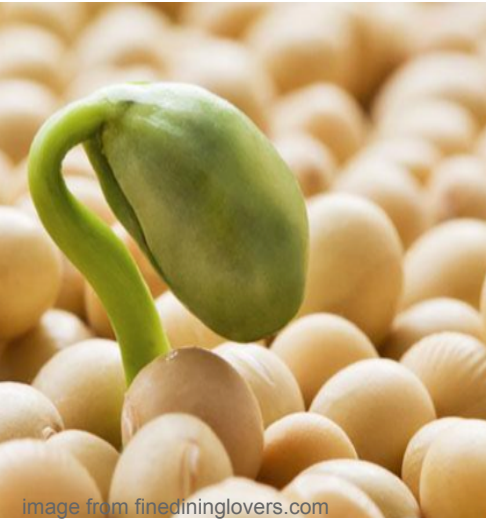
image from finedininglovers.com


image from columbiaforestproducts.com


image from treehugger.com

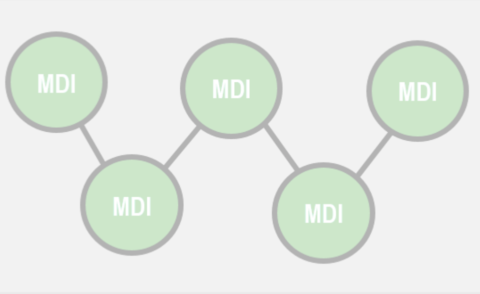
Develop soy-based wood adhesive into a sprayable foam.

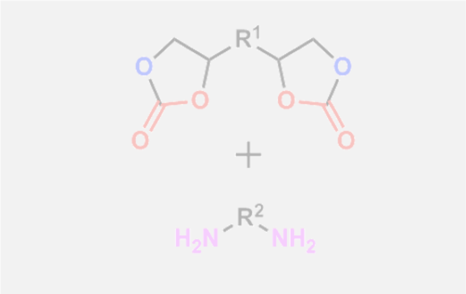
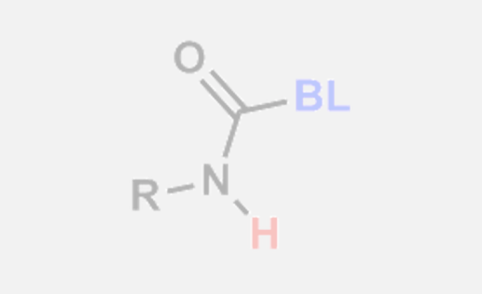
Protein Crosslinking



Protein-based spray foam

- adhesive form currently exists
- soy protein - naturally sourced
- upstream health concerns with precursor chemicals



Polysaccharide Crosslinking



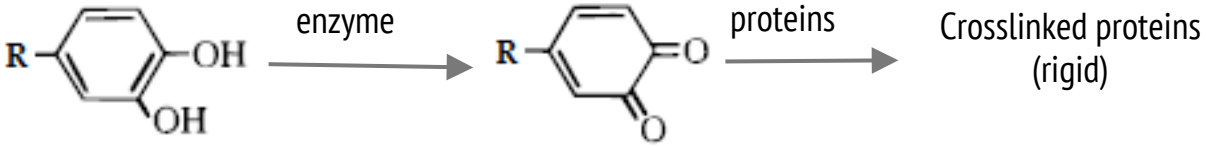

images from societyforsicence.org, staticflickr.com, exteriorsoflansing.com, wageningenur.nl, ibtimes.com

Polysaccharide Crosslinking

Sclerotization

Polysaccharide Crosslinking

Sclerotization



catechol

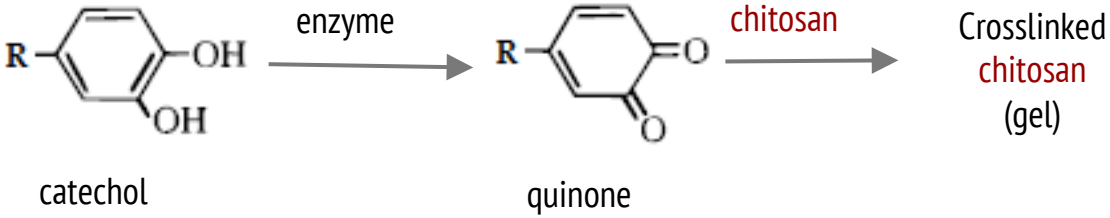
quinone

soft → rigid

Yamada et al. 2000. Biomacromolecules.

Polysaccharide Crosslinking

Strategy: replace proteins with polysaccharides



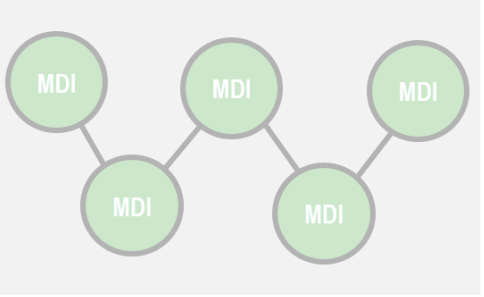
liquid → gel

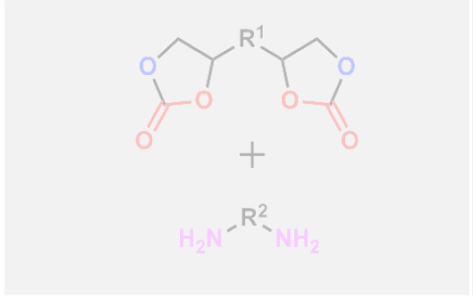
Yamada et al. 2000. Biomacromolecules.

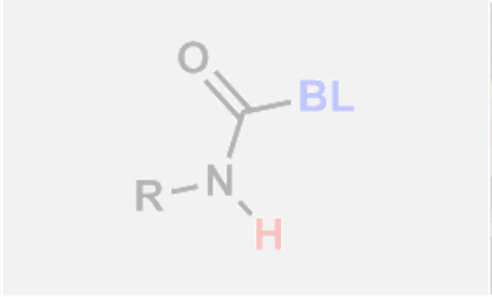
Polysaccharide Crosslinking

Current research:

- hydrogels
- water-resistant adhesives



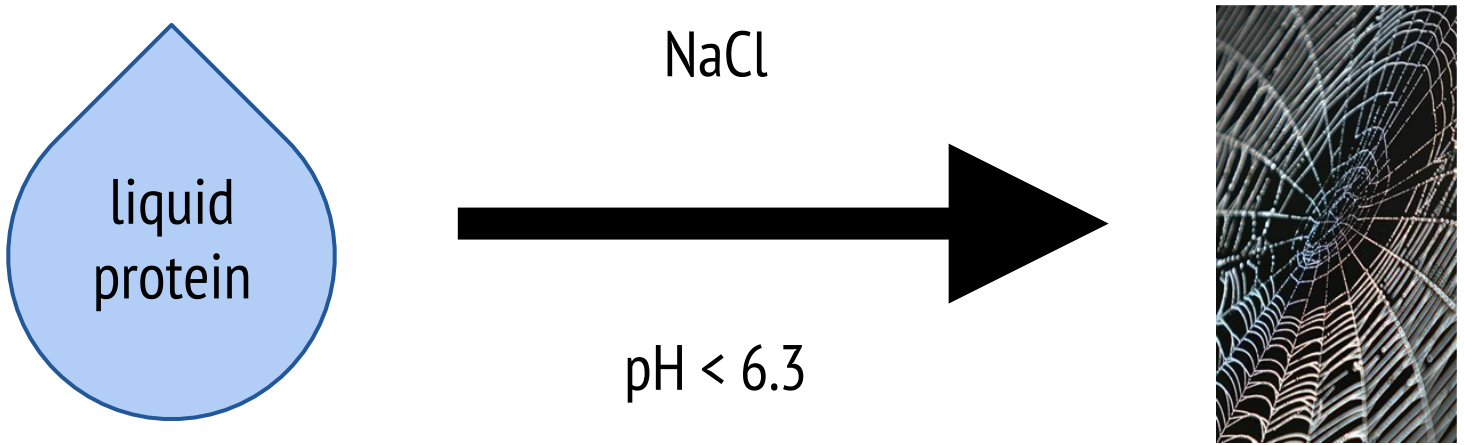


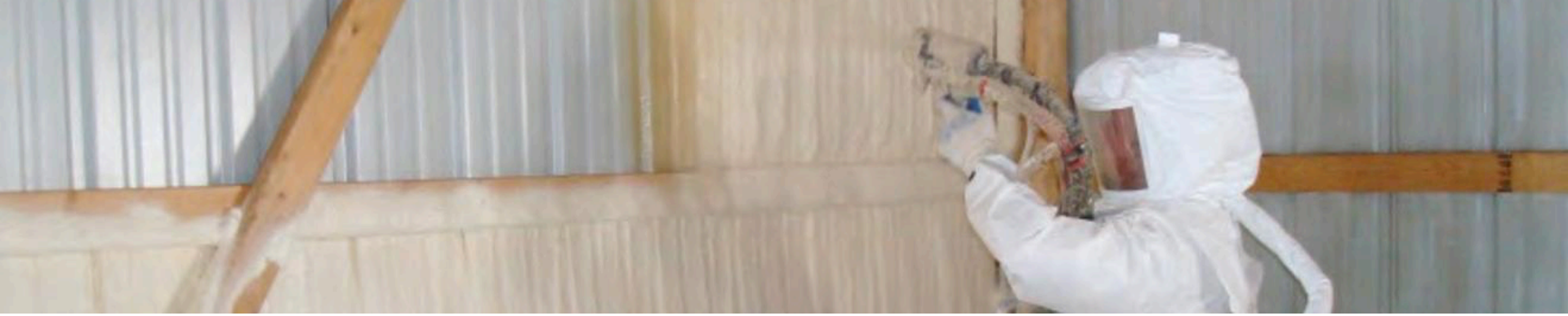


pH Self Crosslinking

images from societyforsicence.org, staticflickr.com, exteriorsofiansing.com, wageningenur.nl, ibtimes.com

pH Self Crosslinking



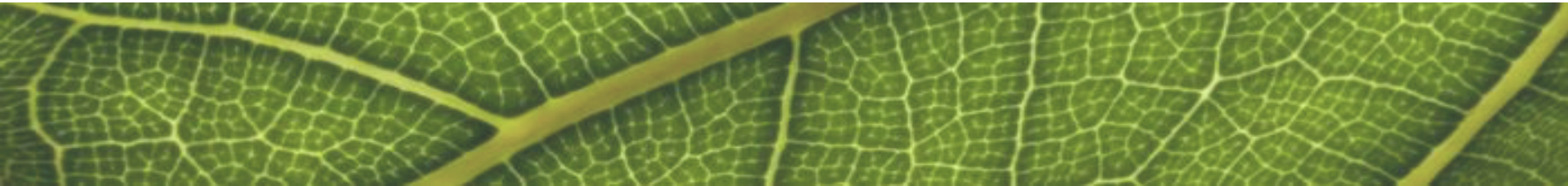


Evaluating Alternatives

Worst 1 2 3 4 Best

* = very uncertain

UNK = unknown



Evaluation Framework – Function

- **Insulation R-value:** “3” = R 6-7/in.
- **Longevity / Stability**: “3” = 20 - 30 years.
- **Sprayability:** “3” = MDI application labor cost, adhesion, cure time
- **Status-Quo Compatibility:** “4” = no change to ingredients, manufacturing methods, application equipment / procedures
- **Fire, Mold, & Pest Resistance:** “4” = better or fewer chemical additives
- **Material Cost:** “3” = MDI total material cost for all ingredients

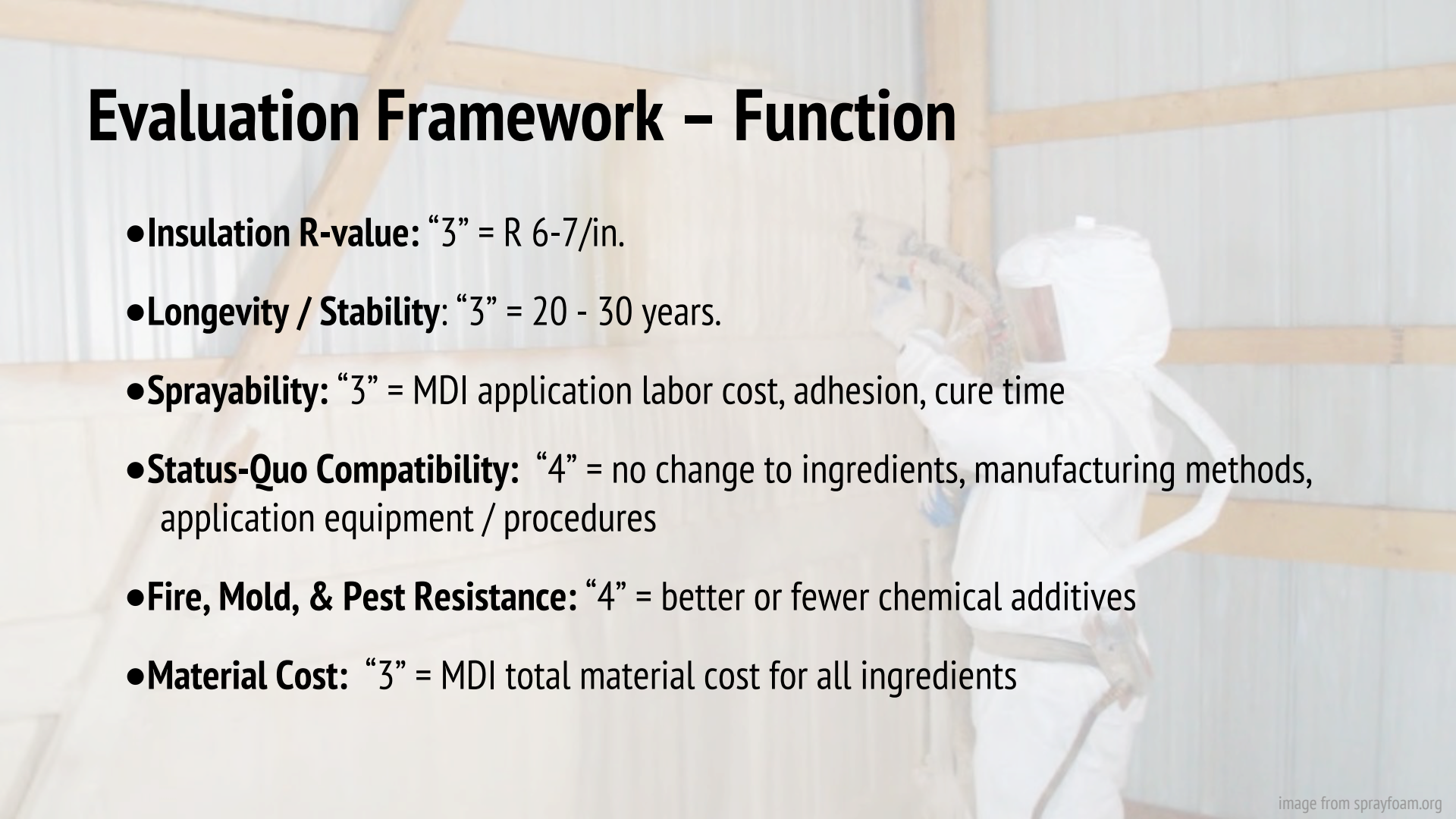


image from sprayfoam.org

Functional Scores

	Insulation R-Value	Longevity / Stability	Sprayability	Status-Quo Compatibility	Fire, Mold, & Pest Resistance	Material Cost	**Overall Functional Score**
MDI (current practice)	3	3	3	4	3	3	**3.2**
Foamed Concrete	2	4	4	3	4	3	**3.4**
Cellulose Spray	2	3	4	3	2	4	**3.2**
Polymeric MDI (pMDI)	3	3	3	3	3	3	**3.0**
Protein Cross-Linking	2 - 4	3	3	2	2 - 3	UNK	**2.5 - 3.0****
Non-Isocyanate Polyurethane (NIPU)	3	3	UNK	2	3	2 - 3	**2.6 - 2.8***
Blocked Isocyanates	3	3	3	2	3	2	**2.7**
Polysaccharide Cross-Linking	UNK	UNK	UNK	1	UNK	UNK	**UNK**
pH Self Cross-Linking	UNK	UNK	UNK	1	UNK	UNK	**UNK**
Percent of Overall Score	15%	20%	20%	15%	10%	20%	

Functional Scores

	Insulation R-Value	Longevity / Stability	Sprayability	Status-Quo Compatibility	Fire, Mold, & Pest Resistance	Material Cost	Overall Functional Score
MDI (current practice)	3	3	3	4	3	3	3.2
Foamed Concrete	2	4	4	3	4	3	3.4
Cellulose Spray	2	3	4	3	2	4	3.2
Polymeric MDI (pMDI)	3	3	3	3	3	3	3.0
Protein Cross-Linking	2 - 4	3	3	2	2 - 3	UNK	2.5 - 3.0**
Non-Isocyanate Polyurethane (NIPU)	3	3	UNK	2	3	2 - 3	2.6 - 2.8*
Blocked Isocyanates	3	3	3	2	3	2	2.7
Polysaccharide Cross-Linking	UNK	UNK	UNK	1	UNK	UNK	UNK
pH Self Cross-Linking	UNK	UNK	UNK	1	UNK	UNK	UNK
Percent of Overall Score	15%	20%	20%	15%	10%	20%	

Functional Scores

	Insulation R-Value	Longevity / Stability	Sprayability	Status-Quo Compatibility	Fire, Mold, & Pest Resistance	Material Cost	**Overall Functional Score**
MDI (current practice)	3	3	3	4	3	3	**3.2**
Foamed Concrete	2	4	4	3	4	3	**3.4**
Cellulose Spray	2	3	4	3	2	4	**3.2**
Polymeric MDI (pMDI)	3	3	3	3	3	3	**3.0**
Protein Cross-Linking	2 - 4	3	3	2	2 - 3	UNK	**2.5 - 3.0****
Non-Isocyanate Polyurethane (NIPU)	3	3	UNK	2	3	2 - 3	**2.6 - 2.8***
Blocked Isocyanates	3	3	3	2	3	2	**2.7**
Polysaccharide Cross-Linking	UNK	UNK	UNK	1	UNK	UNK	**UNK**
pH Self Cross-Linking	UNK	UNK	UNK	1	UNK	UNK	**UNK**
Percent of Overall Score	15%	20%	20%	15%	10%	20%	

Evaluation Framework – Health & Environment

- **Sensitization:** Induces allergic response
- **Acute Toxicity:** Toxic effects for <24 hours of exposure
- **Carcinogenicity or Mutagenicity:** Causes cancer or mutations
- **Endocrine Disruption, Reproductive, or Developmental Toxicity:** Disrupts hormones, reproductive or child development
- **Environmental Toxicity:** Toxic to fish or animals
- **Persistence / Bioaccumulation:** Stays in environment and/or accumulates in bodies

image from photo-dictionary.com

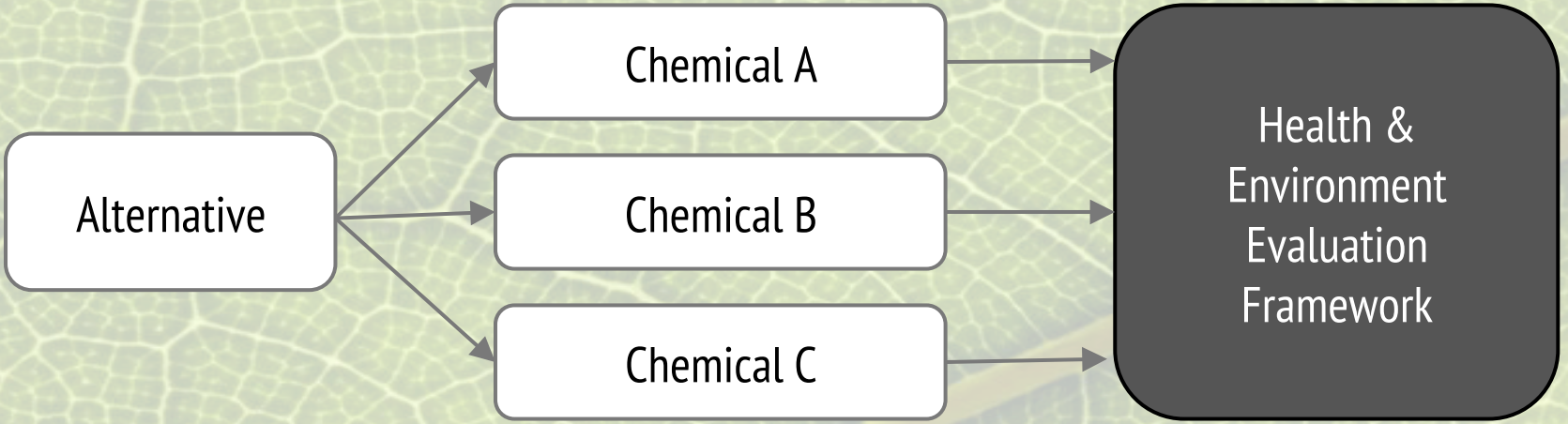


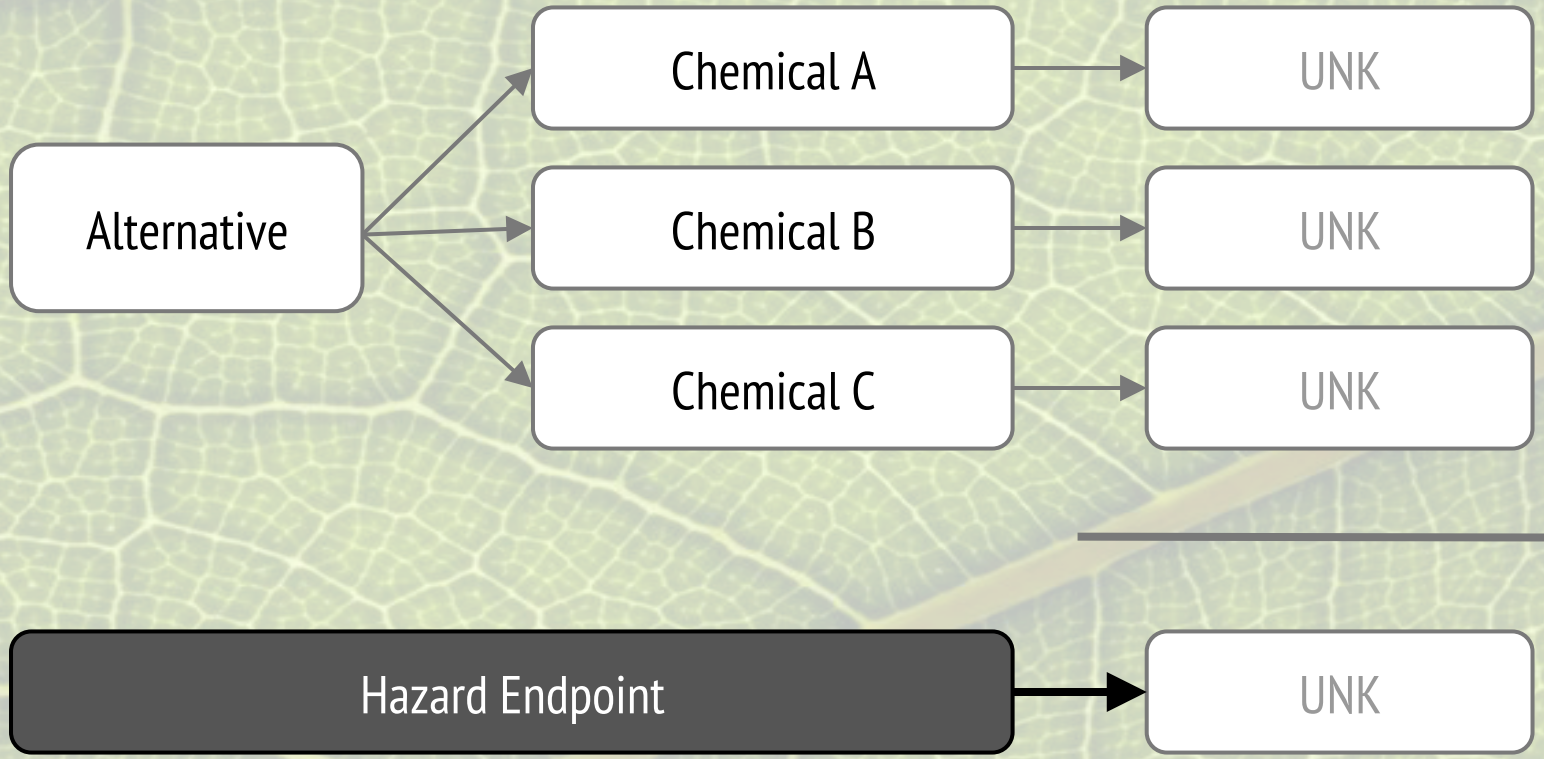
image from photo-dictionary.com

	1	2	3	4
Sensitization				
Acute Toxicity	very high	high	moderate	low
Carc. / Mutag.				
ED, Repr. / Dev.				
Environ. Tox.	very high	high	moderate	low
Persist / Bioacc.	very high	high	moderate	low

image from photo-dictionary.com

	1	2	3	4
Sensitization	known resp.	suspected resp. / known skin	susp skin	probably not
Acute Toxicity	very high	high	moderate	low
Carc. / Mutag.	known	suspected	possible	probably not
ED, Repr. / Dev.	known	suspected	possible	probably not
Environ. Tox.	very high	high	moderate	low
Persist / Bioacc.	very high	high	moderate	low

image from photo-dictionary.com



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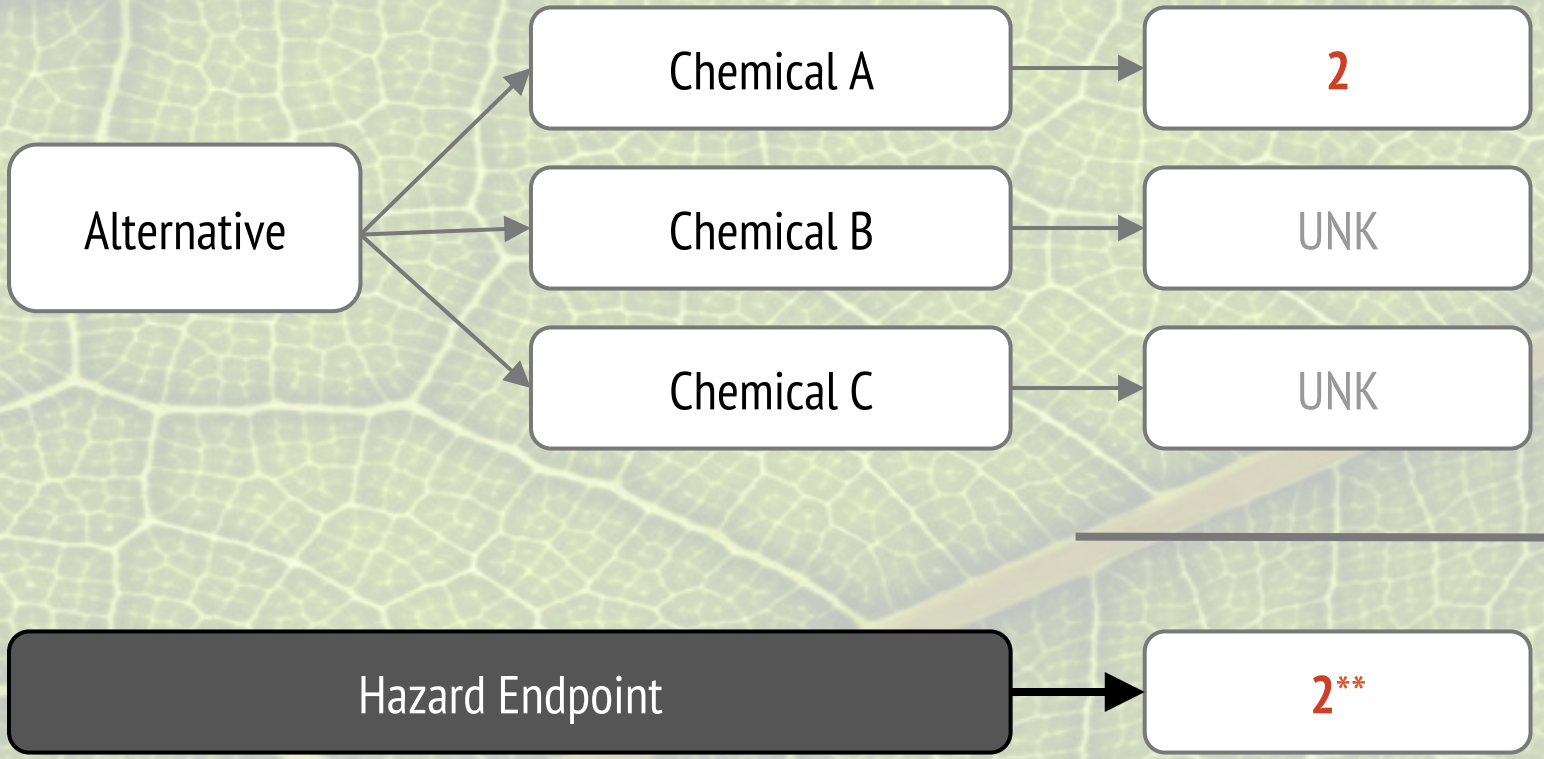

image from photo-dictionary.com

Health & Environment Scores

	Sensitization	Acute Toxicity	Carcinogen / Mutagen	Endocrine / Reproductive / Development	Aquatic Tox / Ecotoxicity	Persistence / Bioaccum.	Overall Health & Env. Score
MDI (current practice)	1	1	2	UNK	UNK	UNK	1.2 – 2.6***
Foamed Concrete	UNK	1 – 4**	UNK	3***	1***	3 – 4*	1.7 – 3.5***
Cellulose Spray	4**	1 – 4*	4**	1 – 4*	1 – 4*	4	2.7 – 4.0***
Polymeric MDI (pMDI)	1	1	UNK	3	UNK	UNK	1.4 – 2.8***
Protein Cross-Linking	2 – 3*	1**	2**	2**	1 – 4*	1**	1.6 – 1.8*
Non-Isocyanate Polyurethane (NIPU)	1 – 3****	1 – 4***	UNK	UNK	1 – 4***	1 – 4*	1.0 – 3.8*****
Blocked Isocyanates	1**	1*	2**	UNK	4**	4**	2.0 – 2.6*
Polysaccharide Cross-Linking	3**	UNK	UNK	UNK	UNK	4**	2.0 – 3.8****
pH Self Cross-Linking	UNK	UNK	UNK	UNK	UNK	UNK	UNK
Percent of Overall Score	20%	15%	20%	20%	15%	10%	

Health & Environment Scores

	Sensitization	Acute Toxicity	Carcinogen / Mutagen	Endocrine / Reproductive / Development	quatic Tox / Ecotoxicity	Persistence / Bioaccum.	Overall Health & Env. Score
MDI (current practice)	1	1	2	UNK	UNK	UNK	1.2 – 2.6***
Foamed Concrete	UNK	1 – 4**	UNK	3***	1***	3 – 4*	1.7 – 3.5***
Cellulose Spray	4**	1 – 4*	4**	1 – 4*	1 – 4*	4	2.7 – 4.0***
Polymeric MDI (pMDI)	1	1	UNK	3	UNK	UNK	1.4 – 2.8***
Protein Cross-Linking	2 – 3*	1**	2**	2**	1 – 4*	1**	1.6 – 1.8*
Non-Isocyanate Polyurethane (NIPU)	1 – 3****	1 – 4***	UNK	UNK	1 – 4***	1 – 4*	1.0 – 3.8*****
Blocked Isocyanates	1**	1*	2**	UNK	4**	4**	2.0 – 2.6*
Polysaccharide Cross-Linking	3**	UNK	UNK	UNK	UNK	4**	2.0 – 3.8****
pH Self Cross-Linking	UNK	UNK	UNK	UNK	UNK	UNK	UNK
Percent of Overall Score	20%	15%	20%	20%	15%	10%	

Health & Environment Scores

	Sensitization	Acute Toxicity	Carcinogen / Mutagen	Endocrine / Reproductive / Development	Aquatic Tox / Ecotoxicity	Persistence / Bioaccum.	Overall Health & Env. Score
MDI (current practice)	1	1	2	UNK	UNK	UNK	1.2 – 2.6***
Foamed Concrete	UNK	1 – 4**	UNK	3***	1***	3 – 4*	1.7 – 3.5***
Cellulose Spray	4**	1 – 4*	4**	1 – 4*	1 – 4*	4	2.7 – 4.0***
Polymeric MDI (pMDI)	1	1	UNK	3	UNK	UNK	1.4 – 2.8***
Protein Cross-Linking	2 – 3*	1**	2**	2**	1 – 4*	1**	1.6 – 1.8*
Non-Isocyanate Polyurethane (NIPU)	1 – 3****	1 – 4***	UNK	UNK	1 – 4***	1 – 4*	1.0 – 3.8*****
Blocked Isocyanates	1**	1*	2**	UNK	4**	4**	2.0 – 2.6*
Polysaccharide Cross-Linking	3**	UNK	UNK	UNK	UNK	4**	2.0 – 3.8****
pH Self Cross-Linking	UNK	UNK	UNK	UNK	UNK	UNK	UNK
Percent of Overall Score	20%	15%	20%	20%	15%	10%	

Conclusion - Recommendations

	Function	Health & Env.
MDI (current practice)	3.2	1.2 – 2.6***
Foamed Concrete	3.4	1.7 – 3.5***
Cellulose Spray	3.2	2.7 – 4.0***
Polymeric MDI (pMDI)	3.0	1.4 – 2.8***
Protein Cross-Linking	2.5 - 3.0**	1.6 – 1.8*
Non-Isocyanate Polyurethane (NIPU)	2.6 - 2.8*	1.0 – 3.8*****
Blocked Isocyanates	2.7	2.0 – 2.6*
Polysaccharide Cross-Linking	UNK	2.0 – 3.8****
pH Self Cross-Linking	UNK	UNK

Conclusion – What We Hope Will Happen

- Assess alternatives more thoroughly
  - Fill gaps in health data
  - Short-term (drop-in)
  - Long-term (research)

- Refine evaluation framework
  - Quantitative metrics for function

Safer Spray-Foam Insulation

Many thanks to:

Marty Mulvihill & Meg Schwarzman,

UC Berkeley Center for Green Chemistry

Will Lorenz, General Coatings

Karl Palmer, CA Department of Toxic Substances Control

Mark Dorfman, Biomimicry 3.8

Heather Palfrey, Center for the Polyurethanes Industry

image from sprayfoam.org